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SURVEY OF DATA ON THE RADIONUCLIDE CONTENT OF FISH IN CANADA

by

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Research report

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ABSTRACT

A computerized database of uranium and thorium decay-series radionuclide concentrations in Canadian fish was compiled, including concentrations of U-total, Th-total, Th-230, Th-232, Th-228, Ra-226, Po-210 and Pb-210 in various fish tissues. Each record represents a specific tissue from a particular fish sample, indexed by province, lake or river of origin, nearest mine/mill, mine status, distance to mill, sampling date, fish species, tissue type, weight basis of measurement, analytical laboratory, and a number of data quality factors. Additional information includes exact location, UTM coordinates, sample collector, literature reference, fish weight, length, age and sex, number of fish, and radionuclide concentrations in water and sediment. Records are retrievable by any combination of index variables, radionuclide ranges and/or data quality criteria.

The majority of the data pertains to Saskatchewan samples, with limited representation of Ontario, British Columbia and the Northwest Territories. Most of the radionuclide measurements are of U-total, Ra-226 and Pb-210. More data are needed for thorium, thorium isotopes and Po-210, and for Ontario samples. Additional recommendations for improvement of the Canadian database in future studies include more detailed documentation of sampling and analytical methods, routine reporting of water and sediment determinations associated with fish samples, and routine sample exchange between laboratories as a means of assessing potential bias and comparability of different data sources.

RÉSUMÉ

Le présent rapport fait état d'une banque de données informatisée qui a été mise sur pied sur les concentrations de radionucléides des séries de désintégration de l'uranium et du thorium, y compris les concentrations d'uranium total, de thorium total, de thorium 230, de thorium 232, de thorium 228, de radium 226, de polonium 210 et de plomb 210 dans divers tissus de poissons. Chaque dossier représente un tissu particulier d'un échantillon précis de poisson, indexé par province, par lac ou rivière d'origine, par mine ou usine de concentration la plus rapprochée, par état des mines, par distance de l'usine de concentration, par date d'échantillonnage, par espèce de poissons, par type de tissus, par base de mesure pour le poids, par laboratoire analytique et par quelques facteurs de qualité des données. Les autres renseignements comprennent l'emplacement exact; les coordonnés PMT; le collecteur d'échantillons; les références; le poids, la longueur, l'âge et le sexe du poisson, ainsi que la concentration de radionucléides dans l'eau et dans les sédiments. On peut consulter les dossiers par n'importe quelle combinaison de variables d'indexation, d'ordre de grandeur des concentrations de radionucléides ou de critères de qualité des données.

La plupart des données proviennent d'échantillons de la Saskatchewan; quelques données seulement proviennent de l'Ontario, de la Colombie-Britannique et des Territoires du Nord-Ouest. La plupart des mesures de radionucléides relèvent de l'uranium total, du radium 226 et du plomb 210. Plus de données sont nécessaires pour le thorium, les isotopes de thorium, le polonium 210 et les échantillons de l'Ontario. Le rapport contient aussi des recommandations pour améliorer la banque de données canadienne aux fins d'études futures, comme de la documentation plus détaillée sur les méthodes d'échantillonnage et d'analyse, les comptes rendus périodiques des teneurs dans l'eau et dans les sédiments associés aux échantillons de poissons, ainsi que les échanges périodiques d'échantillons entre laboratoires comme moyen d'évaluer le biais possible et la comparabilité des différentes sources de données.

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APPENDIX 1: Literature Search and Information Sources

APPENDIX 2: Frequency Distributions of Radionuclide Concentrations in Fish Tissues with Descriptive Statistics

APPENDIX 3: Relationships Between Radionuclides in Fish Tissues with Regression Statistics and Residuals

APPENDIX 4: Listing of DBaseIII Sorting and Retrieval Programs

1.0 INTRODUCTION

1.1 Background

Considerable concern has been expressed by the public about possible health risks of consuming fish from waters affected by uranium mining and milling operations. In order to address these concerns, the Atomic Energy Control Board requires accurate knowledge of radionuclide concentrations in fish species from areas both affected and unaffected by these activities.

Data on radionuclide concentrations in fish species are available from diverse sources, including government agencies, universities, mining companies, consulting firms, analytical laboratories, the published scientific literature and individual scientists. The data are contained in scientific journals, unpublished environmental impact assessments, government reports, conference proceedings, unpublished theses and monitoring reports from operating uranium mines.

As discussed in these reports, fish samples for radionuclide analysis have been taken for a variety of reasons at different times and by different research groups. The samples, therefore, have been analyzed and reported in a variety of ways and units. As a result, inter-comparisons of the data are often difficult.

The "quality" of the data may also be quite variable from one study to another, and indeed within a specific study. Quality in this context refers to several factors, including:

- the collection, handling and storage of the samples;
- the analytical procedures followed;
- the procedures of quality control and quality assurance followed; and
- the occurrence of statistical anomalies (outliers) or values outside the normal range of values in the published Canadian and international literature.

The Atomic Energy Control Board has, therefore, sponsored the compilation of all the readily available data on radionuclide levels in fish from Canadian waters, and entry of

the data into a computerized database, along with a variety of information including the sampling location, the type of tissue analyzed, the species of fish, the distance to the nearest uranium mill and a quality assessment of each measurement. This database will facilitate comparative studies of radionuclide concentrations in fish, and aid in addressing many of the public concerns over potential risks to health in consuming fish from waters near uranium mining and milling operations.

1.2 Objectives

The specific objectives of this study were:

1. To compile the existing data on radionuclide concentrations in fish collected from Canadian waters, particularly in the vicinity of uranium mines and mills. The radionuclides of interest are those of the uranium and thorium decay series, and include U-238, U-234, U-total, Th-230, Th-232, Th-228, Th-total, Ra-228, Ra-226, Po-210 and Pb-210. Along with the concentrations will be included associated information such as the lake or river from which the samples were taken, the length, weight, sex and species of each fish, the tissue analyzed, the weight basis of the measurement, the analytical laboratory and the source or reference where the data were reported.

2. To establish criteria by which the "quality" of the data can be assessed and to evaluate the data by these criteria; and

3. To tabulate the data including the quality assessments and store them in a DBaseIII Plus file. The user of this file will be able to sort the data by key informational factors such as those listed in the first objective to obtain a subset of the database. This subset can then be "dumped" into external files for statistical treatment. The database must also be expandable so that new data can be added to the database as it appears in the literature.

2.0 LITERATURE SEARCH

To compile the database, four general sources of data were consulted. These include:

- o the "in-house" collection of environmental impact studies and relevant reports at BEAK;
- o information retrieval databases;
- o personal communications with scientists and analytical laboratories across Canada; and
- o the environmental monitoring reports of operating uranium mines and unpublished environmental impact assessments available in the AECB library in Ottawa.

All environmental impact assessments and monitoring reports from currently operating, previously operating and proposed uranium mines and mills in Canada that were available were examined. Any additional studies of radionuclides in fish from Canadian waters unaffected by uranium mining/milling were also examined. Water and sediment concentrations, if readily available, were abstracted and included in the database to enable the user to calculate biological concentration factors.

2.1 Information Sources Consulted

2.1.1 Information Retrieval Databases

A computerized literature search was conducted by Mr. Brian Wilks at York University. The following databases were consulted:

- o AQUAREF (formerly CENV and ENV)
- o ASFA
- o ELIAS
- o MINTEC
- o ENG

Key words used in the literature search included the word fish in combination with any of the radionuclides of interest, and also the names of all past and currently operating

uranium mines and mills in Canada. These were included in the literature search because many general environmental studies do not specifically mention the sampling of fish for radionuclides in either the title or the abstract. Most of them, however, mention the uranium mine or mill for which the study was made. A complete list of the key words can be found in Appendix 1.

2.1.2 Personal Communications

Thirty-six analytical laboratories and scientists, listed in Appendix 1, were contacted by telephone and/or mail in a search for unknown, unpublished data or studies. We were also able to obtain information on the laboratories responsible for analyses of samples from the environmental monitoring programs of currently and previously operating uranium mills.

2.2 Contributing Sources

In Appendix 1 is a list of 35 data sources which contributed to the AECB database of fish radionuclide levels in Canada. Included in the listing are the number of fish samples collected, the radionuclides analyzed, and the numeric reference code used for each data source in the database. Complete citations are given in Section 9.0.

3.0 DATA TABULATION

3.1 Information Fields, Formats and Assumptions

The database set up in DBaseIII to contain the radionuclide data on fish consists of 71 informational and 13 quality assessment fields. The 71 informational fields are listed below, in order of occurrence on each record, with the correct DBaseIII abbreviation of each field, an indication as to whether the field is numeric (N) or alphanumeric (A), and the field width. Missing data in numeric fields are indicated as -999 while, in alphanumeric fields, missing data are indicated by blanks or 'none'. The quality assessment fields are listed separately in Section 4.0.

No.	Name of Field	Width	Abbreviation
1	Record Number (N)	9	Record
2	Province/Territory (A)	9	Province
3	Lake (A)	14	LAKE
4	Bay or Location (A)	9	Bay
5	UTM Coordinates (A)	10	UTM
6	Mine (A)	9	MINE
7	Status of Mine (A)	9	STATUS
8	Source - Collection of Sample (A)	9	COLLECTION
9	Source - Analysis of Sample (A)	9	ANALYSIS
10	Source - Literature Reference (A)	9	REFERENCE
11	Fish Species (A)	14	SPECIES
12	Tissue Analyzed (A)	10	TISSUE
13	Distance to Mill (N)	9	DTOMILLKM
14	Fish-Weight (N)	9	FISHWTGM
15	Fish-Length (N)	9	FIHSLENGCM
16	Fish-Age (N)	9	FISHAGEYR
17	Fish-Sex (A)	9	SEX
18	Date of Sample - Month (N)	3	MONTH
19	Date of Sample - Day (N)	3	DAY
20	Date of Sample - Year (N)	3	YEAR
21	Number of Fish in Sample (N)	9	NOOFFISH

No.	Name of Field	Width	Abbreviation
22	Weight Basis (A)	9	WEIGHTBASI
23	Radium-226 in Fish (N)	9	RA226FISH
24	Units (of above) (A)	9	RA226FUNIT
25	Radium-226 in Water (N)	9	RA226H2O
26	Units (of above) (A)	9	RA226HUNIT
27	Radium-226 in Sediment (N)	9	RA226SED
28	Units (of above) (A)	9	RA226SUNIT
29	Lead-210 in Fish (N)	9	PB210FISH
30	Units (of above) (A)	9	PB210FUNIT
31	Lead-210 in Water (N)	9	PB210H2O
32	Units (of above) (A)	9	PB210HUNIT
33	Lead-210 in Sediment (N)	9	PB210SED
34	Units (of above) (A)	9	PB210SUNIT
35	Uranium-total in Fish (N)	9	URANTFISH
36	Units (of above) (A)	9	URANTFUNIT
37	Uranium-total in Water (N)	9	URANTH2O
38	Units (of above) (A)	9	URANTHUNIT
39	Uranium-total in Sediments (N)	9	URANTSED
40	Units (of above) (A)	9	URANTSUNIT
41	Sediment/Water Reference (A)	9	WATSEDREF
42	Polonium-210 in Fish (N)	9	PO210FISH
43	Units (of above) (A)	9	PO210FUNIT
44	Polonium-210 in Water (N)	9	PO210H2O
45	Units (of above) (A)	9	PO210HUNIT
46	Polonium-210 in Sediment (N)	9	PO210SED
47	Units (of above) (A)	9	PO210SUNIT
48	Thorium-230 in Fish (N)	9	TH230FISH
49	Units (of above) (A)	9	TH230FUNIT
50	Thorium-230 in Water (N)	9	TH230H2O
51	Units (of above) (A)	9	TH230HUNIT
52	Thorium-230 in Sediments (N)	9	TH230SED
53	Units (of above) (A)	9	TH230SUNIT
54	Thorium-total in Fish (N)	9	THORTFISH

No.	Name of Field	Width	Abbreviation
55	Units (of above) (A)	9	THORTUNIT
56	Thorium-total in Water (N)	9	THORTH2O
57	Units (of above) (A)	9	THORTUNIT
58	Thorium-total in Sediments (N)	9	THORTSED
59	Units (of above) (A)	9	THORTSUNIT
60	Thorium-232 in Fish (N)	9	TH232FISH
61	Units (of above) (A)	9	TH232FUNIT
62	Thorium-232 in Water (N)	9	TH232H2O
63	Units (of above) (A)	9	TH232HUNIT
64	Thorium-232 in Sediments (N)	9	TH232SED
65	Units (of above) (A)	9	TH232SUNIT
66	Thorium-228 in Fish (N)	9	TH228FISH
67	Units (of above) (A)	9	TH228FUNIT
68	Thorium-228 in Water (N)	9	TH228H2O
69	Units (of above) (A)	9	TH228HUNIT
70	Thorium-228 in Sediments (N)	9	TH228SED
71	Units (of above) (A)	9	TH228SUNIT

Those informational fields which are not self-evident and require additional description are described in the following sections.

3.1.1 Record Number

Each record represents a specific tissue from a particular fish sample (either an individual fish or composite of several fish) designated by a number with one decimal place. The whole number to the left of the decimal is a sample number, while each decimal fraction indicates a different tissue and weight basis combination.

3.1.2 Province/Territory

Four provinces/territories are included in the database: Sask., Ont., NWT, B.C.

3.1.3 Lake

Sixty-one water bodies are identified in this field, as follows:

Beaverlodge	Marian	McDonald	Donaldson
Fredette	Bow Lake	Delta	Schmoo
Milliken	Paudash	Russell	Dunlop
W1	Kewen	Gunnar Pit	Esten
Shallow	Joan	Horseshoe	Depot
Waterbury	Lassie	Kewen	Quirke
Henday	Clark	Key	McCarthy
McMahon	Sandrift (1 and 2)	Wheller R.	Huron
Midwest	Trapper	Cluff	Teasdale
Hatchet	Trapping Cr.	Cumberland	Whiskey
Wollaston	Beaverdell Cr.	Sandy	Pecors
Collins Cr.	ELA (7 numbers)	Island	Elliot
C1	Ace Cr.	Great Bear	Camp
McClean	Fulton	Snake	Serpent H.
Tailings Cr.	Athabasca	Dubyna	Ontario
Sherman			

For record retrieval purposes (Section 5.0), both Sandrift Lakes, and all ELA lakes, are retrieved as sets.

3.1.4 UTM Coordinates

The longitude and latitude of each lake or river were either estimated directly from standard topographic maps or by consulting with the following gazetters and atlases:

- Gazetteer of Canada, Saskatchewan, Geographical Services Division, Energy, Mines and Resources, Ottawa, 1969, 1985
- Gazetteer of Canada, N.W.T., Geographical Services Division, Energy, Mines and Resources, Ottawa, 1980
- Gazetteer of Canada, British Columbia, Geographical Services Division, Energy, Mines and Resources, Ottawa, 1985
- Gazetteer of Canada, Ontario, Geographical Branch, Energy, Mines and Resources, Ottawa, 1962
- Goode's World Atlas, 12th Edition, Rand McNally and Co., Chicago, 1968

The coordinates are given to the nearest minute in a ten-character code, with the latitude preceding the longitude. For example, the coordinates 45°53' north latitude, 108°25' west longitude would appear as 4553/10825.

In the case of lakes or bays on lakes, the coordinates are taken from the centre of these features. For rivers and creeks, the coordinates are taken from the creek or river mouth. When a sampling station is described as being on a particular lake off a given town or city, the coordinates given are those of the town or city.

3.1.5 Mine

This field provides the name of the mine or mill in the vicinity of the site where the fish were sampled. Most mines (or proposed mines) are listed by their most common name. In the case of lakes influenced by several surrounding mines, a collective name is used; for example, the name "Elliot Lake" is used to define a large number of mines in the vicinity of the Town of Elliot Lake, Ontario.

The following mines are found in the database:

Mine Name	Abbreviation
Midwest Lake Saskatchewan, Canada Wide Mines Ltd.	Midwest
Beaverlodge Mining Operations, Eldorado Resources Ltd.	Eldorado
Rabbit Lake Mining Operations, Eldor Mines (Eldorado Resources Ltd.)	Rabbit Lake
Lorado/Gunnar Uranium Mines	Lor./Gun.
Key Lake, Saskatchewan, Key Lake Mining Corp.	Key Lake
Elliot Lake (includes Quirke, Denison, Spanish/American, Stanrock, CANMET, Panel Stanleigh, Milliken, Lacnor)	Elliot
Gunnar Uranium Mine	Gunnar
Bancroft (includes Faraday, Bicroft, Dyno)	Bancroft
Project Wolly-McClean, Canadian Occidental Petroleum	Wolly

Mine Name	Abbreviation
Blizzard Uranium Property, Norcen	Blizzard
Cluff Lake Uranium Mine, Amok Ltd.	Cluff Lake
Collins Bay B-Zone, Eldor Mines (Eldorado Resources Ltd.)	B-Zone
Dubyna Mine, Eldorado Resources Ltd.	Dubyna
Rayrock Mine, N.W.T.	Rayrock

3.1.6 Mine Status

The status of the mine/mill refers to the operational status of the mine at the time the samples were taken. Mine status is coded by the numbers 1, 2 or 3. Number 1 refers to a mine or mill that is pre-operational. In this case, the data usually comes from a baseline monitoring or environmental impact study of a proposed mine or mill site. Samples taken from bodies of water unaffected by uranium mining were also placed in this category. Number 2 refers to an operational mine or mill, while Number 3 refers to a mine or mill that is already decommissioned or in the process of being decommissioned.

3.1.7 Source - Collection of Sample
Source - Analysis of Sample

These two alphanumeric fields supply the name of the research group or company responsible for collecting the fish samples and analyzing the samples respectively. The following is a list of the sample collectors and analyzing laboratories:

Sample Collectors/Analytical Laboratories	Abbreviation
Saskatchewan Research Council, Saskatoon, Saskatchewan	SRC
Atomic Energy Control Board Laboratories, Ottawa, Ontario	AECB
Atomic Energy of Canada Ltd., Chalk River Nuclear Laboratories, Chalk River	AECL
Ontario Department of Health, currently Ministry of Health	MOH
Environment Canada, Wastewater Technology Centre	EC-WTC

Sample Collectors/Analytical Laboratories	Abbreviation
Environment Canada, National Water Research Institute	EC-NWRI
Chemex Labs, Calgary	Chemex
Freshwater Institute, Winnipeg, Manitoba	FWI
Gulf Minerals Canada Ltd.	Gulf Min
Monenco Analytical Laboratories, Calgary Alberta	Monenco
Beak Consultants Limited, Mississauga, Ontario	BEAK
Integrated Environmental Sciences Inc., Saskatoon, Saskatchewan	IES
Environmental Protection Service, Environment Canada	EPS
Ontario Ministry of Natural Resources	MNR
Senes Consultants Ltd., Willowdale, Ontario	SENES
Stearns-Roger Canada	Stearns R.
Ontario Water Resources Commission (now part of Ontario Ministry of the Environment)	OWRC
MacLaren Plansearch Inc.	MacLaren
Eldorado Nuclear Resources	Eldorado
Key Lake Mining Corporation	KLMC
Envirocon Ltd.	Envirocon
Cluff Lake Uranium Mine, Amok Ltd.	CLUM
M. Kalin, Institute for Environmental Studies, University of Toronto	Kalin

3.1.8 Source - Literature Reference

This alphanumeric field provides a numeric code indicating the correct reference or report from which the data were extracted. The references are listed by this numeric code in Appendix 1. The complete citations are given in Section 9.0.

3.1.9 Fish Species

This field presents the species of fish from which each sample was taken. Data are available from the 24 species of fish listed below, with their scientific names and abbreviations used in the database:

Common Name	Abbreviation	Scientific Name
Lake Trout	L. TROUT	Salvelinus namaycush (Walbaum)
Northern Pike	N. PIKE	Esox lucius (Linnaeus)
Lake Whitefish	WHITEFISH	Coregonus clupeaformis (Mitchill)
Arctic Grayling	GRAYLING	Thymallus arcticus (Pallas)
Lake Chub	L. CHUB	Couesius plumbeus (Agassiz)
Common Sucker	SUCKER	Catostomus commersoni (Lacepede)
Walleye	WALLEYE	Stizostedion vitreum (Mitchill)
Round Whitefish	R. WHITEFISH	Prosopium cylindraceum (Pallas)
Longnose Sucker	L.N. SUCKER	Catostomus catostomus (Forster)
Brown Bullhead	B. BULLHEAD	Ictalurus nebulosus (Lesueur)
Yellow Perch	Y. PERCH	Perca flavescens (Mitchill)
Gizzard Shad	G. SHAD	Dorosoma cepedianum (Lesueur)
Brown Trout	B. TROUT	Salmo trutta (Linnaeus)
Alewife	ALEWIFE	Alosa pseudoharengus (Wilson)
Rainbow Trout	R. TROUT	Salmo gairdneri (Richardson)
Sturgeon	STURGEON	Acipenser fluvescens (Rafinesque)
Bass	BASS	Micropterus sp.
Pearl Dace	P. DACE	Semotilus margarita (Cope)
Fathead Minnow	F. MINNOW	Pimephales promelas (Rafinesque)
Northern Redbelly Dace	N.R. DACE	Chrosomus eos (Cope)
Ninespine Stickleback	N. STICKLEBACK	Pungitius pungitius (Linnaeus)
Cisco	CISCO	Coregonus artedii (Lesueur)
Trout Perch	T. PERCH	Percopsis omiscomaycus (Walbaum)
Spottail Shiner	S. SHINER	Notropis hudsonius (Clinton)

3.1.10 Fish Weight, Length, Age

Fish weights are expressed in grams, lengths in cm, and age in years. In composite samples, the mean weight, length and age are given when available.

3.1.11 Tissue Analyzed

This alphanumeric field describes the fish tissue on which the radionuclide analyses were done. The categories of tissue in the database are abbreviated and grouped as follows. For purposes of data retrieval, using the sorting program of Section 5.0, only the eight major tissue groups below are recognized. Tissue categories within these groups are not distinguished by the program.

Tissue	Abbreviation
bone	bone
bone plus scales plus flesh	bone,sc,fl
flesh (without skin)	flesh
flesh plus skin (not scaled)	flesh,skin
flesh plus skin (scaled)	flesh(sk)
gonad	gonad
gut	gut
liver	liver
skin	skin
skin plus bone	skin,bone
stomach	stomach
whole fish	W
whole fish (washed)	W(Wd)
etc.	

When the whole fish was analyzed, often the case for small forage species, samples were treated in a variety of ways. Samples were reported as washed (Wd) or unwashed (Uw), gutted (g) or ungutted (U), or as cross-sections of the fish (Xsect). All of these variations were considered to be whole fish samples.

When sorting records on the basis of tissue type, the sorting program only recognizes the first few characters in the tissue field, as indicated by the underlining in the Abbreviation column above.

3.1.12 Distance to Mill

The distance to the mill or mine was estimated from topographic maps to the nearest kilometre. In cases where the tailings are alongside or occupying part of the lake from which the fish samples were taken, the distance-to-mill was assumed to be zero. For control sites upstream of a mill or mine, the distances are expressed as negative numbers. Whenever possible, the distances were measured along natural drainage patterns rather than straight-lines to reflect the natural dispersion of potential contaminants. Sites unaffected by uranium mining (i.e., lying entirely outside the drainage basin of a mill) are indicated as +999, while missing data are indicated by -999 as in other fields.

3.1.13 Weight Basis

The weight basis refers to the method of expressing the radionuclide concentrations in each fish sample. Radionuclide levels are expressed on a wet weight, dry weight or ash weight basis, indicated by the words wet, dry or ash in this field.

3.1.14 Radionuclide Concentrations in Fish/Units

Two fields were assigned to express the concentration of each radionuclide in fish tissue. The first, a numeric field, gives the numerical value, and the second, an alphanumeric field, gives the units in which the concentrations are expressed. Concentrations below the detection limit, often appearing as a "less than" quantity in the literature (for example, ≤ 0.005 pCi/L), are expressed as negative numbers. This was done to maintain the numeric character of the field for record retrieval based on concentration ranges and for future statistical manipulations.

In a few cases (e.g., EPS, 1986b), concentrations of radionuclides in fish were reported as "zero", thereby implying that concentrations were below an unstated detection limit and not statistically different from zero. When this occurred and, in the single case (OWRC,

(OWRC, 1971) when concentrations were reported simply as "below detection", a value of "zero" was maintained in the database. These data were flagged in a specific quality assessment field (discussed in Section 4.2) to warn the user against incorporating these values in statistical analyses of the data.

Radionuclide levels are expressed in units of pCi/g, pCi/kg or Bq/g, as reported. Because total uranium and thorium are normally measured by fluorometric rather than radiocounting techniques, these radionuclides are expressed as ug/g or ppm. The sorting program of Section 5.0 adjusts to common units of Bq/g or ug/g to permit record retrieval in a specified concentration range.

3.1.15 Radionuclide Concentrations in Water and Sediments

Whenever available, radionuclide concentrations in the water and sediments were included with the concentrations in the fish, primarily to enable the user to calculate biological concentration factors. Since water and sediment samples were often taken more frequently and in more locations than the fish samples, and often not at exactly the same point as the fish, average values for the lake or bay were calculated and reported in the database. In calculating averages, "less than" values were taken as the value of the indicated detection limit, thus biasing the averages high. The units of the water and sediment concentrations were recorded in separate alphanumeric fields. The units in water were pCi/L, Bq/L, or ug/L (ppb) in the case of total uranium and thorium. Radionuclide concentrations in sediments were expressed as Bq, pCi or ug per gram of sediments. In most studies, it was not indicated whether concentration per gram dry weight or wet weight of sediments was intended. When available, this information was indicated in the units field as W.W. (wet weight) or D.W. (dry weight).

3.1.16 Sediment/Water Reference

The alphanumeric field indicates the report or reference in the literature from which the water and sediment data are derived. The same numeric code system is used as in the fish reference field above (Section 3.1.5). In most cases, the radionuclide levels in the water and sediments were derived from the same reference as the fish concentrations. The references corresponding to each numeric code are listed in Appendix 1, with complete citations in Section 9.0.

4.0 DATA QUALITY EVALUATION

Since the fish samples in the database were collected for a variety of purposes by different research groups and analyzed by different laboratories, it is to be expected that the quality of the data will vary considerably. "Quality" in this context refers to several factors, including:

1. sample collection protocol;
2. sample handling and storage;
3. the analysis techniques employed;
4. the quality control practices associated with sample analysis;
5. explicit statement of relative errors and detection limits; and
6. the existence of anomalous values or statistical outliers.

These "concerns" were distilled to create a series of quality assessment criteria used to evaluate each fish sample (record). Two types of criteria were identified:

1. criteria based on procedure and documentation; and
2. criteria based on statistical evaluation of the data themselves.

Based on these criteria, the following data quality fields were created:

Quality Fields Based on Procedure and Documentation

No.	Field	Abbreviation
1	Sampling procedure	DQSAMP
2	Method of sample storage	DQSTORE
3	Tissue source	DQTS
4	Biological preparation	DQBP
5	Analytical procedure	DQAP
6	Weight basis given	DQWBG
7	Blanks/standards	DQBLK

No.	Field	Abbreviation
8	Detection limit	DQDL
9	Relative error	DQRE

Quality Fields Based on Statistical Evaluation of the Data

10	Outliers based on radionuclide relationships in tissue	DQ-RATIO
11	Outliers based on concentrations in tissue	DQ-CONC
12	Concentrations reported as zero	DQRF
13	Bioconcentration factors beyond normal range of the literature	DQBCFL

The following sections include a detailed discussion of each field.

4.1 Quality Fields Based on Procedure and Documentation

The nine quality fields based on procedure and documentation of the data are discussed in separate sections below.

Much of the information required for completing these fields was not obtained from the fish studies themselves, in which methods were often poorly described, but from personal communications, letters, phone calls, etc. Especially helpful was the study conducted by BEAK (1985) to develop a procedure for evaluating the quality of environmental data. In this study a survey was made of the methods and quality control procedures employed in Canadian laboratories responsible for the majority of chemical and radiochemical analyses of environmental samples. It must be recognized that, even though a laboratory reports following specific quality control procedures as a general practice, it does not necessarily mean that these procedures were followed exactly with particular samples. Furthermore, even after a considerable expenditure of effort, information to complete the quality fields was sometimes lacking. In some cases, this lack of information cast an element of suspicion on the procedures employed and lowered the quality assessment score.

4.1.1 Sampling Procedure

Sampling procedures and subsequent handling of the fish samples are not well described in the literature. In almost 50% of the cases, the sampling method itself, whether by gill netting, seine netting or another method, is not mentioned at all. It is generally considered to be good sampling practice to document the methods employed in order to allow users of the data to judge possible routes of sample contamination. The following scoring system was established:

- o Sampling Method Described — Score: 2
- o Sampling Method Not Described — Score: 1

4.1.2 Storage Method

As part of the normal handling of biological samples, the method and the duration of storage of each tissue sample are extremely important. Chemical preservatives such as formalin which might permit the leaching of radionuclides from the fish material into the preservative should be avoided.

Freezing was the most common and best method of preservation, although freeze-drying was used in at least one reported case (Joshi, 1984). In no case was the reported method of storage considered to be inappropriate. In the majority (70%) of cases, however, no reference at all is made to the storage method or to the period of time the samples were kept before analysis. The following scoring procedure was established.

- o Method of Sample Storage Reported and Appropriate — Score: 2
- o Method of Sample Storage Not Reported — Score: 1
- o Method of Sample Storage Inappropriate — Score: 0

4.1.3 Tissue Source

Different fish tissues are known to accumulate different quantities of radionuclides (Swanson, 1983). It is therefore extremely important to report the tissue used in any analysis in order that results from different studies can be compared. Because of the variety of purposes behind the various studies, samples were taken of a large number of tissue types (described in Section 3.1.11).

In many studies, these samples were not taken of single tissues, but of several tissues in combination. Although these tissue mixtures were often consistent with the goals of the individual studies, they rendered difficult any comparison of the data between studies. Especially difficult were tissue combinations with bone because bone accumulates a higher concentration of many radionuclides than other tissues (Swanson, 1983). A sample composed of bone plus scales plus flesh in unknown proportions cannot easily be compared with bone or scales or flesh samples. The quality field was, therefore, set up based on a criterion of comparability. Samples containing combinations of tissues involving bone were labelled as incomparable with other samples. The following scoring system was established:

- Tissue Type Known and Comparable with Other Samples — Score: 2
- Tissue Type Unknown — Score: 1
- Tissue Type Incomparable with Other Samples — Score: 0

Most studies received the maximum score (2) in this quality field. In only one study did the authors fail to mention the tissue type (score = 1). In 26 records, the tissue type was labelled as incomparable with other tissue samples.

4.1.4 Biological Preparation

One of the most important steps in any radiochemical analysis is the decomposition of the sample matrix which must be dissolved completely and the elements of interest converted to proper ionic form before the analysis can proceed. The accuracy of the radiochemical analysis will depend on the choice of the method of sample decomposition (Monenco, 1984), since decomposition can influence sample geometry during counting, as well as chemical reactivity and volatilization.

Biological samples are normally decomposed by either dry or wet ashing. In dry ashing, the sample is heated to decompose the organic material while, in wet ashing, the sample is attacked with oxidizing acids (e.g., nitric, perchloric).

Both methods of digestion were considered acceptable in the database, although dry ashing was used in the majority of the samples. Since a loss of polonium can occur at the high temperatures of dry ashing (CANMET 78-22), wet ashing was considered necessary

in analyses of this radionuclide. In all but five studies, the methods of sample decomposition were known, and considered acceptable. The data were scored as follows:

- o Method of Biological Preparation Known and Appropriate — Score: 2
- o Method of Biological Preparation Unknown — Score: 1
- o Method of Biological Preparation Inappropriate — Score: 0

4.1.5 Analytical Procedures

This quality assessment field judges the acceptability of the radiochemical procedures used by each laboratory to analyze the fish samples. The most serious obstacle in assessing the quality of the data produced by a particular laboratory is the lack of a common reference standard of fish material for analyzing elements of the uranium and thorium decay series. This problem was recognized by the National Uranium Tailings Program (BEAK, 1985), which attempted to establish a reference collection of fish material. The project, however, was abandoned because levels of these radionuclides in the fish material were too low to be useful, and a suitable method of storing this material could not be found. As a result, no absolute measure of bias is available, and we are forced to assess the data on the basis of the methodologies used and whether suitable quality assurance procedures were followed in each laboratory.

The acceptability of the analytical procedures were judged using methods outlined in CANMET 78-22 and Monenco (1984) as standard methods. Like the tissue source, the analytical procedures were scored as follows:

- o Analytical Procedure Known and Appropriate — Score: 2
- o Analytical Procedure Unknown — Score: 1
- o Analytical Procedure Inappropriate — Score: 0

In most cases (89%), analyses were done using acceptable techniques. In two studies, an outline of the analytical procedures could not be obtained (score: 1) while, in one study (Kalin, 1984), the analytical procedures were judged inappropriate (score: 0), because the laboratory (AECB, Ottawa) had never before analyzed fish material for radionuclides, and the data obtained were viewed as unreliable even by the analytical laboratory (Elizabeth Laishly, pers. comm.). Some data reported by Kalin (1984) were actually

excluded from the database because the project manager of this study (David Southerland, EPS) indicated that the suspected data should be considered anomalous (David Southerland, pers. comm. to AECB).

4.1.6 Weight Basis Given

Failure to provide the weight basis by which a radionuclide concentration was calculated (per gram wet weight, dry weight, or ash) seriously reduces the usefulness of the measurement. For this reason, the following scoring system was established:

- o Weight Basis Known — Score: 1
- o Weight Basis Unknown — Score: 0

The weight basis was reported for all but one study.

4.1.7 Blanks/Standards

This data quality field judges the quality control and quality assurance procedures followed by each analytical laboratory on the basis of whether blanks and reference standards were analyzed with the samples and with what frequency. These reference standards refer only to counting standards of each radionuclide since reference fish material is unavailable. Most of the information for completing this field is derived from personal communications and BEAK (1985). As discussed above (Section 4.0), the accuracy of this field will depend entirely on the accuracy of the information supplied by each laboratory. The laboratories were scored as follows:

- o Blanks/Standards Used and Their Frequency Known — Score: 2
- o Blanks and Standards Used, Frequency Unknown — Score: 1
- o No Information Available on Blanks/Standards — Score: 0

Most studies scored well in this field. For three laboratories (AECB, Gulf Minerals and MOH), no information was available on the use of blanks and standards. In two other laboratories (FWI, EC-NWRI), blanks and standards were used, but no information was available on their frequency of use.

4.1.8 Detection Limit

Detection limits may actually be sample-specific, based on repeatability of low-level measurements in a particular matrix. Nevertheless, an average or approximate generic detection limit is useful in judging the significance of reported data. Values reported far below the detection limit may not be distinguishable from zero, and may be viewed with suspicion by the data user. In order to treat low-level data from different sources consistently, the user must know how detection limits have been calculated. The method of calculating the detection limit should be reported and should follow established statistical procedures (see ASTM, 1985). The data were, therefore, scored as follows:

- o Detection Limit Given; Calculation Described and Appropriate — Score: 2
- o Detection Limit Given; Calculation Not Described — Score: 1
- o Radionuclide Concentration Reported is Less Than a Stated Detection Limit — Score: 0

Most of the detection limits provided in the literature are sample-specific detection limits for which no explicit explanation is given. These are inferred from the "less than" values in the data. Because these detection limits are given without description, they received a score of one. In only one case (Norcen, 1980) was a generic detection limit reported. However, its method of calculation was not described.

4.1.9 Relative Error

In order to assess the statistical and biological significance of the fish radionuclide data, it is useful to know the relative error associated with each measurement. At least two sources of variability (error) occur in these samples. The first results from the inherent variability of biological samples. To estimate this error, it would be necessary to calculate the standard deviation of measurement on replicate samples from different fish from the same location. The second source of error can be called analytical, and is associated with the chemical extractions required to isolate the radionuclide(s) of interest, and with the radiocounting technique. This error can be estimated by calculating the standard deviation of replicate samples from the same fish. Although relative errors were reported in 83% of the studies, it was never described how they were

calculated. Quite likely, these errors reported are radiocounting errors obtained from the counting statistics of the radiocounting system employed. The following scoring system was established:

- o Relative Error Stated (or available) and Defined — Score: 2
- o Relative Error Stated (or available) but Not Defined — Score: 1
- o Relative Error Not Stated (or available) — Score: 0

4.2 Quality Fields Based on Statistical Evaluation of the Data

Data quality can be assessed by identifying statistically anomalous values or outliers in the database. Identification of outliers is a more objective measure of data quality than quality factors based on analytical procedures or documentation (Section 4.1) because it involves less subjective judgement as to whether or not procedures are appropriate. The outlier criteria depend only on the definition of each statistical population and on assumptions about the form of its frequency distribution. It must be remembered that measurements identified as outliers may still represent real heterogeneity within the data set. The user must decide on a case-by-case basis whether to include outliers in data summaries or calculations. Whether the user chooses to include or exclude outlier values, it is important that he be aware of their existence.

The decision regarding outlier inclusion should be based on several considerations:

1. Is there any known reason other than sampling/analytical error (e.g., sample location relative to known radionuclide sources) that might account for the anomalous value? If so, has the data set been defined in a logical manner, or would it be more realistic to treat it as several distinct data sets?
2. How sensitive are the intended calculations to the presence of outliers? For example, outlier inclusion may result in non-normal frequency distributions which invalidate parametric statistical tests.

In order to identify outliers, statistical populations were defined within the database on the basis of lake name, fish species, tissue type and weight basis of concentrations. Appropriate combinations of these categories within a particular study were considered

as separate populations. All populations, having ten or more observations for a particular radionuclide, were subjected to outlier analysis. Records containing outlying radionuclide concentrations were identified in one of four fields. These fields are described in the following sections.

4.2.1 Outliers Based on Concentrations in Tissues

This quality field identifies values statistically different from the other values within a defined population. Since radionuclide concentrations in tissues tend to follow assymmetric, logarithmic distributions, each population was transformed logarithmically to normalize its distribution and improve its symmetry. Means (M) and standard deviations (S) of the log values were then computed, and outlier limits defined as:

$$M \pm 3S$$

In a normal distribution, 99% of observed values should fall within these limits. Any records with values of any radionuclide in fish tissue above or below these limits were flagged with a zero value in the corresponding data quality field. Other records were assigned a value of one in this field. Radionuclide concentrations reported as less than some specified value, presumably the level of detection, and concentrations reported as "zero" were excluded from these calculations.

Frequency distributions are presented graphically in Section 6.0 and Appendix 2, with means, standard deviations, outlier limits and other descriptive statistics. Records identified as outliers are listed in Table 4.1.

4.2.2 Concentrations Reported as Zero

Radionuclide concentrations reported as zero in tissues were flagged automatically in this data quality field with a quality score of zero. These values should have been expressed by the authors as less than some specified detection limit or instrument response threshold or, if "zero" represents the instrument response, the value should have been flagged and the detection limit stated. Radionuclide concentrations of zero value were not included in the calculations used to identify the concentration outliers (Section 4.2.1). Table 4.2 lists the records flagged for zero concentrations on one or more radionuclides.

4.2.3 Outliers Based on Radionuclide Relationships in Tissues

Relationships between concentrations of two radionculides in particular fish tissues can also be used to identify anomalous samples. Frequently, radionuclides occur in specific ratios within a given tissue. The relationship can be defined by a linear regression equation of the form:

$$Y = a + b X$$

where: Y is the dependent radionuclide concentration,
X is the independent radionuclide,
b is the regression coefficient approximating the Y/X ratio, and
a is a constant near zero.

A residual is calculated for each sample point as the distance from the point to the regression line, on the Y axis. The residuals tend to be more normally distributed than the individual concentrations X and Y. Outliers from the residual distribution represent anomalous samples.

Populations for residual analysis were defined as previously described, with unique combinations of lake name, fish species, tissue type and weight basis. Pairs of radionuclides, for which ten or more pairwise observations existed, were tested for significant relationships within each population. A significant ($p < 0.05$) relationship was found between Ra-226 and Pb-210 in eight different data sets. Residuals from these relationships were calculated, and residual distributions were characterized by a mean (M) and standard deviation (S).

Outlier limits for each residual distribution were defined as:

$$M \pm 2S$$

In a normal distribution, 95% of observed residuals should fall within these limits. Any records with residuals above or below these limits were flagged with zero values in the corresponding data quality field. Other records were assigned a value of one in this field.

The limit of two standard deviations used for pairwise residuals is a more stringent outlier criterion than the limit of three standard deviations used for individual radionuclide concentrations. This reflects the fact that the residuals follow the normal distribution more closely and consistently than the log concentrations. Thus, there is greater confidence in the outlier classification based on residuals.

Records identified as outliers based on this criterion are listed in Table 4.3. In the case of the Tailings Creek Lake Chub population, several outlier samples were flagged by the author (Swanson, 1982). These same samples were determined to be outliers based on residual analysis. Details of residual analysis for each significant Ra-226/Pb-210 relationship, including regression statistics and extreme residual values, are included in Appendix 3.

As described in Section 4.2.1, radionuclide concentrations reported as zero values, or as less than a specified detection limit, were excluded from residual analysis. Zero concentrations were flagged in a separate data quality field (Section 4.2.2).

4.2.4 Bioconcentration Factors Beyond Literature Range

Bioconcentration factors (BCF's) relative to water concentrations were computed for all records having both fish tissue and water concentrations of the same radionuclide. These values were compared to the BCF ranges reported in the world literature, in order to detect any 'out-of-range' values. Outlying values were flagged with zero values in this quality field.

Literature values of bioconcentration factors utilized to construct acceptable BCF ranges for radium, uranium and lead in different fish tissues are listed in Table 4.4. Acceptable ranges are summarized in Table 4.5, both on wet weight and ash weight bases. Wet weight BCF ranges are derived directly from the literature. Ash weight BCF ranges are derived from the wet weight ranges, assuming a fixed ash percentage by weight in each tissue. Ash percentages published by Swanson (1983) range from a low of 1% in most fish soft tissues to approximately 20% in bone. Sediment-based bioconcentration factors for fish and water-based bioconcentration factors for thorium and polonium were not considered sufficiently common in the literature to establish any realistic range for comparison.

Table 4.6 summarizes the distribution of BCF values resulting in outlier flags in the database. Overall, it is clear that more high values than low values are flagged, which is consistent with a logarithmic distribution of bioconcentration factors. The literature values, on which acceptable ranges are based, are often calculated from sample means, and thus may be expected to exhibit some central tendency. Positive deviations from such a centralized range are more likely than negative deviations in a logarithmic distribution.

4.3 A Composite Data Quality Index

With 13 separate data quality fields, it is difficult for the user to decide which records are acceptable or unacceptable for his own purposes. In general, records with high scores in all the data quality fields contain data which are thoroughly documented and entirely reasonable in relation to other data from the same locality and the published literature. Records with zero scores in the data quality fields contain some data which are open to question, though not necessarily erroneous. Most of the data in the database, however, are associated with at least some quality scores of intermediate value. For each record, the user is confronted with a complex array of quality factors, some of which he may consider more relevant to his purposes than others.

Designation of a minimum acceptable level of data quality or documentation is a subjective decision, which is and should be dependent on the intended application of the data. For example, data intended for use in litigation must be completely documented in order to stand up in court. For food-chain models incorporating uncertainty factors, less stringent acceptability criteria are probably more appropriate. However, acceptability criteria will still depend on such factors as the intended use and potential consequences of model predictions, as well as the quantity of data available.

Reduction of all data quality information to a single composite index representing overall confidence in the data as applies to a given use would be of great advantage to some users. Obviously, this index would be calculated based on subjective decisions concerning the relative importance of each data quality factor. Such an index can be calculated within the database. The index is computed as a weighted sum of the scores in the different data quality fields. The weighting factors are specified by the user, and may vary between 0 and 1. The weighted index is normalized to a range between 0 and 10 and rounded to the nearest integer.

The index calculations have been included as an option in the DBaseIII macro command SORTER. The SORTER macro is invoked in DBaseIII by typing the command DO SORTER in response to the dot prompt (see Section 5.0). The user then replies to a series of questions on data retrieval strategy, one of which gives him the option of computing a composite data quality index. If he chooses this option, the user is prompted to enter the weighting factors. He can subsequently retrieve records based on the value of the computed index.

Records can also be retrieved based on values in any of the individual outlier fields described in Section 4.2. This retrieval option is included in the SORTER macro command previously described. An example of data retrieval based on data quality flags is provided in Table 4.7. A full description of data retrieval and sorting capabilities is given in Section 5.0.

TABLE 4.1: OUTLIERS[1] BASED ON RADIONUCLIDE CONCENTRATIONS IN FISH TISSUES

Record No.	Population	Population Size	Outlier Direction[1]	Radionuclide
81.1	Ace Creek, Sucker, whole, ash	16	Low	Uranium
92.5	Beaverlodge L., Whitefish, bone, ash	42	Low	Uranium
93.5	Beaverlodge L., Whitefish, bone, ash	42	Low	Uranium
92.3	Beaverlodge L., Whitefish, flesh, ash	39	Low	Uranium
107.1	Beaverlodge L., Whitefish, skin, ash	36	Low	Radium-226
131.1	Beaverlodge L., Whitefish, skin, ash	40	Low	Uranium
298.2	Beaverlodge L., Whitefish, flesh, wet	31	High	Radium-226
298.2	Beaverlodge L., Whitefish, flesh, wet	33	High	Lead-210
298.2	Beaverlodge L., Whitefish, flesh, wet	39	High	Uranium
131.2	Beaverlodge L., Whitefish, skin, wet	41	Low	Uranium
136.5	Milliken Lake, Sucker, bone, ash	19	High	Lead-210
151.1	Milliken Lake, Sucker, skin, ash	24	High	Radium-226
136.1	Milliken Lake, Sucker, skin, ash	20	High	Lead-210
160.1	Milliken Lake, Sucker, skin, ash	36	High	Uranium
150.6	Milliken Lake, Sucker, bone, wet	18	Low	Lead-210
145.4	Milliken Lake, Sucker, flesh, wet	31	High	Uranium
145.2	Milliken Lake, Sucker, skin, wet	21	High	Lead-210
163.2	Milliken Lake, Sucker, skin, wet	36	Low	Uranium

[1] Single outliers beyond range defined by population mean ± 3 standard deviations.

TABLE 4.2: RECORDS WITH ZERO CONCENTRATIONS OF RADIONUCLIDES IN FISH TISSUE

Record Number	Population	Radionuclide(s)
107.4	Beaverlodge Lake, Whitefish, flesh, wet	Ra-226
108.4	Beaverlodge Lake, Whitefish, flesh, wet	Ra-226
111.4	Beaverlodge Lake, Whitefish, flesh, wet	Ra-226
144.4	Milliken Lake, Sucker, flesh, wet	Ra-226
149.4	Milliken Lake, Sucker, flesh, wet	Ra-226
152.4	Milliken Lake, Sucker, flesh, wet	Ra-226
155.4	Milliken Lake, Sucker, flesh, wet	Ra-226
156.4	Milliken Lake, Sucker, flesh, wet	Ra-226
158.4	Milliken Lake, Sucker, flesh, wet	Ra-226
168.4	Milliken Lake, Sucker, flesh, wet	Ra-226
170.4	Milliken Lake, Sucker, flesh, wet	Ra-226
175.4	Milliken Lake, Sucker, flesh, wet	Ra-226
186.4	Fredette Lake, Whitefish, flesh, wet	Ra-226
188.4	Fredette Lake, Whitefish, flesh, wet	Ra-226
194.4	Fredette Lake, Whitefish, flesh, wet	Ra-226
411	Lake Ontario, B. Bullhead, flesh, wet	Ra-226, Th-230, Th-232
412	Lake Ontario, Y. Perch, flesh, wet	Th-232
413	Lake Ontario, Y. Perch, flesh, wet	Th-232
414	Lake Ontario, Y. Perch, flesh, wet	U
415	Lake Ontario, Y. Perch, flesh, wet	Th-232
416	Lake Ontario, G. Shad, flesh, wet	U, Th-232
418	Lake Ontario, G. Shad, flesh, wet	Pb-210
419	Lake Ontario, G. Shad, flesh, wet	Ra-226, Pb-210, U, Th-232
420	Lake Ontario, G. Shad, flesh, wet	Ra-226, Pb-210
421	Lake Ontario, N. Pike, flesh, wet	Ra-226, U, Th-230, Th-232
422	Lake Ontario, B. Trout, flesh, wet	Ra-226, Pb-210, U, Th-232
423	Lake Ontario, B. Trout, flesh, wet	Ra-226, Pb-210, Th-230, Th-232
424/425	Lake Ontario, B. Trout, flesh, wet	Ra-226, Pb-210, U, Th-230, Th-232, Th-228
426	Lake Ontario, B. Trout, flesh, wet	Ra-226, Pb-210
427.1	Lake Ontario, Sucker, flesh, wet	Pb-210, Th-232
427.2	Lake Ontario, Sucker, flesh, bone, skin, wet	Pb-210
428.1	Lake Ontario, L. Trout, flesh, wet	Ra-226, Pb-210, Th-230, Th-232
428.2	Lake Ontario, L. Trout, flesh, bone, skin, wet	Ra-226, Pb-210, U, Th-232, Th-228
429.1	Lake Ontario, L. Trout, flesh, wet	Ra-226, Pb-210, Th-232
429.2	Lake Ontario, L. Trout, flesh, bone, skin, wet	Pb-210, U, Th-232
430	Lake Ontario, Alewife, whole, wet	Th-232
494.1	Teasdale Lake, Whitefish, whole (Xsect), wet	Ra-226, U
494.2	Teasdale Lake, Whitefish, flesh, wet	Ra-226, U
495.1	Teasdale Lake, L. Trout, whole, wet	Ra-226
496.2	Dunlop Lake, Whitefish, whole, wet	Ra-226
497.1	Dunlop Lake, L. Trout, whole, wet	Ra-226
497.2	Dunlop Lake, L. Trout, flesh, wet	Ra-226, U
500.2	Whiskey Lake, Whitefish, flesh, wet	Ra-226
501.1	Whiskey Lake, L. Trout, whole, wet	Ra-226
504.2	Elliot Lake, L. Trout, flesh, wet	U
505.2	Depot Lake, Whitefish, flesh, wet	Ra-226
506.2	McCarthy Lake, Walleye, flesh, wet	U
508.2	Camp Lake, Whitefish, flesh, wet	Ra-226
851	Ganaraska River, R. Trout, flesh, wet	Pb-210
852	Ganaraska River, R. Trout, flesh, wet	Pb-210, Th-232
853	Ganaraska River, R. Trout, flesh, wet	Pb-210

TABLE 4.3: OUTLIERS[1] BASED ON RESIDUALS FROM RADIUM-226:LEAD-210 RELATIONSHIP

Record No.	Population	Population Size	Outlier Direction[1]	Standardized Residual
151.2	Milliken Lake, Sucker, skin, wet	13	High	+ 2.75
131.2	Beaverlodge Lake, Whitefish, skin, wet	36	High	+ 2.38
131.1	Beaverlodge Lake, Whitefish, skin, ash	35	High	+ 2.63
86.2	Ace Creek, Sucker, whole, wet	14	High	+ 3.00
86.1	Ace Creek, Sucker, whole, ash	15	High	+ 2.13
126.7	Beaverlodge L., Whitefish, stomach, wet	26	High	+ 2.13
101.7	Beaverlodge L., Whitefish, stomach, wet	26	Low	- 2.38
64.2*	Tailings Creek Lake Chub, whole, wet	18	High	+ 2.88
48.2*	Tailings Creek Lake Chub, whole, wet	18	High	+ 2.38
48.1*	Tailings Creek, Lake Chub, whole, ash	18	High	+ 2.75
64.1*	Tailings Creek, Lake Chub, whole, ash	18	High	+ 2.38

[1] Outliers beyond range defined by population mean residual ± 2 standard deviations.

* Outliers flagged by author (Swanson, 1982).

TABLE 4.4: PUBLISHED VALUES OF RADIONUCLIDE BIOCONCENTRATION FACTORS IN VARIOUS FISH TISSUES

Radionuclide	Flesh	Bone	Liver	Skin	Whole	Reference
Uranium	10	-	-	-	-	Thompson et al., 1972
	2	-	-	-	-	U.S. NRC, 1977
	0.7-38	-	-	-	-	Stegner & Kobal, 1982
	0.3-38	-	-	-	-	Blaylock, 1982
	10	-	-	-	-	IAEA, 1982
	0.2-18	20-189	0.4-38	-	-	AECB, 1984
	10	75	20	-	-	AECB, 1984
	0.1-25	21-800	-	3-150	6.1-12.7	Swanson, 1985
Thorium	30	-	-		-	U.S. NRC, 1977
	30	-	-		-	IAEA, 1982
	30	-	0.7-3,281		-	AECB, 1984
		-	30		-	AECB, 1984
		-	-		150	IAEA, 1976
Lead-210	100	-		-	-	U.S. NRC, 1977
	0.5-150	-		-	-	Thompson et al., 1972
	9	275		-	-	IAEA, 1976
	15-76	150-1,227	4-1,600	-	-	AECB, 1984
	40	700	600	-	-	AECB, 1984
	5-100	117-2,500	-	33-650	300-700	Swanson, 1985
		300	-	-	-	IAEA, 1982

TABLE 4.4: PUBLISHED VALUES OF RADIONUCLIDE BIOCONCENTRATION FACTORS IN VARIOUS FISH TISSUES

Radionuclide	Flesh	Bone	Liver	Skin	Whole	Reference
Polonium-210	500	-				U.S. NRC, 1977
	300	-				Thompson et al., 1972
	500	640				IAEA, 1976
	50	-				IAEA, 1982
	30-830	138				AECB, 1984
Radium-226	3-4	100	-	-	-	Anderson et al., 1963
	1-14	-	-	-	2-11	OWRC, 1971
	100-600	500-5,000	-	-	-	Pradel and Zettwoog, 1977
	50	-	-	-	-	U.S. NRC, 1977
	7.4	60	-	-	54	Ruggles and Rowley, 1978
		-	-	-	3-60	CEA, 1979
	50	-	-	-	-	Thompson et al., 1972
	18	-	-	-	-	Schuttelkopf and Kiefer, 1982
	3-8	39-50	-	-	-	Markose et al., 1980
	42-137	-	-	-	-	Stegner and Kobal, 1982
	0.3-137	-	-	-	-	Blaylock, 1982
	13-119	-	-	-	-	Williams, 1984
	1.4-60	35-1,800	-	2-520	620-980	Swanson, 1985
	10	-	-	-	-	IAEA, 1982
	3-27	36-750	11-1,500	-	-	AECB, 1984
	12	400	50	-	-	AECB, 1984

TABLE 4.5: ACCEPTABLE RANGES OF RADIONUCLIDE BIOCONCENTRATION FACTORS USED TO GENERATE OUTLIER FLAGS

Radionuclide[1]	Tissue	Wet Weight BCF	% Ash	Ash Weight BCF
Radium-226	Flesh	1-600	1	100-60,000
	Bone	10-5,000	20	50-25,000
	Liver	3-1,500	2	150-75,000
	Skin	1-520	1	100-52,000
	Whole	2-980	1	200-98,000
Uranium	Flesh	0.1-38	1	10-3,800
	Bone	2-800	20	10-4,000
	Liver	0.4-150	2	20-7,500
	Skin	0.4-150	1	40-15,000
	Whole	0.1-38	1	10-3,800
Lead-210	Flesh	0.5-150	1	50-15,000
	Bone	8-2,500	20	40-12,500
	Liver	4-1,600	2	200-80,000
	Skin	2-650	1	200-65,000
	Whole	2-700	1	200-70,000

[1] Records were not flagged based on bioconcentration factors for radionuclides other than radium-226, uranium and lead-210.

TABLE 4.6i DISTRIBUTION OF OUTLIERS BASED ON VALUES OF BIOCONCENTRATION FACTORS

Population	Records with Outlier Flags
Henday Lake, Northern Pike, whole, ash	3
Wollaston Lake, Whitefish, flesh, wet	28
Tailings Creek, Lake Chub, whole, wet	48.2, 55.2, 56.2, 64.2
Tailings Creek, Lake Chub, whole, ash	50.1 304
Tailings Creek, Sucker, whole, wet	59.2
Tailings Creek, Sucker, whole, ash	305, 307
Beaverlodge Lake, Whitefish, flesh, wet	92.4, 94.4, 95.4, 103.4, 106.4, 107.4, 108.4, 109.4, 111.4, 112.4, 127.4, 298.2
Beaverlodge Lake, Whitefish, flesh, ash	92.3, 94.3, 95.3, 101.3, 103.3, 106.3, 109.3, 125.3
Beaverlodge Lake, Whitefish, liver, wet	96.8, 109.8, 118.8
Beaverlodge Lake, Whitefish, skin, ash	107.1, 131.1
Beaverlodge Lake, Whitefish, bone, ash	107.5, 122.5
Beaverlodge Lake, Whitefish, bone, wet	107.6, 122.6
Beaverlodge Lake, Whitefish, skin, wet	114.2, 115.2, 129.2, 131.2, 298.1
Beaverlodge Lake, Sucker, skin, wet	299.1
Beaverlodge Lake, Sucker, flesh, wet	299.2
Fulton Lake, Whitefish, skin, wet	300.1
Fulton Lake, Sucker, skin, wet	301.1
Fulton Lake, Sucker, flesh, wet	301.2
Lake Athabasca, Northern Pike, flesh, ash	336, 338, 343
Gunnar Pit, Northern Pike, flesh, ash	446.1, 447.1, 448.1
Gunnar Pit, Northern Pike, bone, ash	446.2, 447.2, 448.2
Dunlop Lake, Whitefish, flesh, wet	496.2
Dunlop Lake, Lake Trout, flesh, wet	497.2
Quirke Lake, Lake Trout, flesh, wet	499.2
Whiskey Lake, Whitefish, flesh, wet	500.2
Pecors Lake, Whitefish, flesh, wet	502.2
Depot Lake, Whitefish, flesh, wet	505.2
Camp Lake, Whitefish, flesh, wet	508.2
McDonald Lake, Lake Trout, flesh, ash	534.1, 535.1
McDonald Lake, Northern Pike, flesh, ash	538.1, 539.1
McDonald Lake, Whitefish, flesh, ash	564.1, 565.1
Key Lake, Northern Pike, flesh, ash	556.1
Key Lake, Whitefish, flesh, ash	562.1, 563.1
Key Lake, Whitefish, bone, ash	562.2
Cluff Lake, Lake Trout, flesh, ash	634.1
Cluff Lake, Lake Trout, bone, ash	636.2
Cluff Lake, Northern Pike, bone, ash	640.2, 641.2
Dubyna Lake, Northern Pike, flesh, ash	772.1
Fredette Lake, Whitefish, flesh, wet	186.4, 188.4, 190.4
Fredette Lake, Whitefish, liver, wet	176.8, 177.8, 180.8, 186.8, 190.8, 193.8
Fredette Lake, Whitefish, skin, wet	177.2, 182.2, 186.2, 190.2
Fredette Lake, Whitefish, skin, ash	187.1
Fredette Lake, Whitefish, bone, wet	177.6, 186.6, 189.6
Fredette Lake, Whitefish, bone, ash	177.5, 186.5
Milliken Lake, Sucker, bone, ash	136.5, 137.5, 145.5, 160.5
Milliken Lake, Sucker, bone, wet	136.6, 137.6, 140.6, 142.6, 145.6, 170.6
Milliken Lake, Sucker, liver, wet	139.8, 142.8, 143.8, 145.8, 149.8, 150.8, 153.8, 162.8, 166.8, 169.8, 171.8, 172.8
Milliken Lake, Sucker, skin, wet	141.2, 142.2, 145.2, 159.2
Milliken Lake, Sucker, skin, ash	160.1
Milliken Lake, Sucker, flesh, wet	144.4, 145.4, 147.4, 149.4, 152.4, 155.4, 156.4, 158.4, 161.4, 168.4, 170.4, 175.4
Milliken Lake, Sucker, flesh, ash	147.3
Sherman Lake, Northern Pike, skin, wet	847, 849

TABLE 4.7: RETRIEVAL OF RECORDS CONTAINING OUTLIER CONCENTRATIONS OF RADIONUCLIDES IN FISH TISSUE

Welcome to the Atomic Energy Control Board's database
on radionuclide levels in fish from Canadian waters.

Is file to be sorted by radionuclides, Y/N? N
Is file to be sorted by Provinces or Territories, Y/N? N
Is file to be sorted by fish species, Y/N? N
Is file to be sorted by tissue type, Y/N? N
Is file to be sorted by analytical lab, Y/N? N
Is file to be sorted by weight basis, Y/N? N
Is file to be sorted by distance to mill, Y/N? N
Is file to be sorted by the date, Y/N? N
Do you want to do calcs on the quality data, Y/N? Y
Are all the quality factor weights the same, Y/N? Y
Sort on the outlier fields, Y/N? Y
Sort on outlier ratio, Y/N? N
Sort on outlier concentration, Y/N? Y
What is the number, 0 (yes) or 1 (No)? 0
Sort on outlier BCF literature, Y/N? N
Sort on radionuclide zero flag, Y/N? N
Sort on total weighted score for data quality, Y/N? N

5.0 DATA RETRIEVAL AND SORTING

The database and DBaseIII Plus programs are backed up on six diskettes. The database file is named AECB4.DBF and all program files have a .PRG extension. The database is restored to the hard disk using the DOS RESTORE command. The programs are restored using the DOS COPY command in the DBaseIII sub-directory. It is suggested that 4 MB of hard disk space be allocated for DBaseIII use in a dedicated sub-directory. The database occupies approximately 1.6 MB. Copies produced during sorting can require a similar volume of disk space, and the remaining space is occupied by DBaseIII programs.

DBaseIII has built-in sorting and retrieval functions, which can be invoked using the Assistant menu. These are adequately described in the DBaseIII manual. However, complex retrieval criteria require the use of a large number of DBaseIII commands in a correct sequence. Extensive knowledge of these commands, and of the database structure, format and spelling conventions, would be required to rely totally on built-in functions for sorting and retrieval.

A macro command program (SORTER.PRG) was therefore developed in order to increase the range of data retrieval and sorting options, and to make this increased capability available to users unfamiliar with DBaseIII. This macro is linked to other programs on diskette, which are automatically called as required in response to user option selections. Full program listings are given in Appendix 4.

To initiate DBaseIII, the DBASE command is given while inside the DBase subdirectory. This leaves the Assistant menu displayed on the screen. The user can either follow the menu, or press the ESC key to access user programs. DBase displays a dot prompt to indicate that user programs are accessible. (Typing Assist will cause the Assistant menu to return.)

To initiate sorting and retrieval in user mode, two commands are given, following the dot prompt. First, SET DEFAULT TO C, then DO SORTER. (The default setting remains in effect throughout the DBase session and can be omitted on subsequent sorting runs).

The user is then asked a series of questions pertaining to sorting strategy. The questions require either a Y or N answer. Questions are arranged hierarchically so that few questions need to be answered when the retrieval strategy is simple. The program can be

terminated at any time by pressing the ESC key. On normal completion of the program, the dot prompt returns automatically.

Sorting and retrieval are possible according to alphanumeric values or numeric ranges in a large number of data fields, or any combination of those fields, as follows:

1. **Radionuclides** - the user is first asked whether he wishes to sort by radionuclides. If the answer is Y, he is asked to select any or all radionuclides and to specify a range of concentrations in fish tissue, water or sediment as a retrieval criterion for each of these radionuclides (values less than detection, while coded negative, are retrieved with a positive range specification). When several radionuclide criteria are specified the record must satisfy all criteria in order to be retrieved.

2. **Provinces** - the user is first asked whether he wishes to sort by provinces. If the answer is Y, he is asked to specify which provinces. Any or all provinces may be selected.

3. **Lakes** - the user is first asked whether he wishes to sort by lakes. If the answer is Y, he is asked to select specific lakes within provinces. In order to be retrieved the specified lakes must be within one of the provinces previously selected, if the province is also used as a sorting/retrieval criterion.

4. **Mines** - the user is first asked whether he wishes to sort by mines. If the answer is Y, he is asked to select any or all mines/mills. In order to be retrieved the selected mines/mills must reside near one of the lakes and in one of the provinces previously selected if lakes and provinces are also used as sorting/retrieval criteria.

5. **Mine Status** - the user is first asked whether he wishes to sort by mine status. If the answer is Y, he is asked to specify a status for each mine (e.g., operational, pre-operational, decommissioned). Status can be specified only for mines previously selected for retrieval. Only one status for each mine may be chosen.

6. **Fish Species** - the user is first asked whether he wishes to sort by fish species. If the answer is Y, he is asked to select any or all species.

7. **Tissue Type** - the user is first asked whether he wishes to sort by tissue type. If the answer is Y, he is asked to select any or all tissue types.

8. **Analytical Laboratory** - the user is asked whether he wishes to sort by laboratory. If the answer is Y, he is asked to select any or all laboratories.

9. **Weight Basis** - the user is asked whether he wishes to sort according to the weight basis on which radionuclide concentrations in tissue are expressed. If the answer is Y, he is asked to select a particular weight basis (e.g., ash, dry or wet weight basis) or weight basis combination.

10. **Distance to Mill** - the user is asked whether he wishes to sort by distance to mill. If the answer is Y, he is asked to specify an acceptable range of distances. This range will apply globally to all mines/mills. The distance range in km may extend from the large negative to the large positive end of the distance scale. Negative distances indicate samples collected upstream of the nearest mine/mill.

11. **Sampling Date** - the user is asked whether he wishes to sort by sampling date. If the answer is Y, he is asked to specify an acceptable range of months or years.

12. **Composite Data Quality Index** - the user is asked whether he wishes to sort according to the value of the composite data quality index (Section 4.3). If the answer is Y, he is asked to provide weighting factors for each data quality field (any fields to be excluded from the computation are given a weight of zero). Weighting factors should range from 0 to 1. The composite index is a weighted sum ranging from 0 to 10. The user is next asked to specify an acceptable index range for retrieval.

13. **Outlier Flags** - the user is asked whether he wishes to sort by outlier status. The question is asked for each outlier field (e.g., concentrations, zero concentrations, ratios or bioconcentration factors). If the answer is Y for any field, the user is asked to specify an acceptable flag value for that field (0 or 1). To exclude outliers, a value of 1 is specified.

The sorting procedure operates on a copy of the original data file. The copy is called AECB5.DBF. Once sorting is completed this file will contain the selected records. These records will be arranged in groups according to the values of all sorting criteria invoked by the user in answering Y to a sorting strategy question.

The sorted file will contain only those data records which meet all criteria specified by the user. Records are deleted from the file whenever they fail to meet a specified criterion.

The sorted file contains all data fields, including those not used as sorting criteria. Data tables containing all fields or a subset of fields can be generated from the sorted file, using the DBaseIII Assistant menu. Such tables can be directed either to the screen, to the printer or to another file on hard disk (drive C) or diskette.

The sorted file can be subjected to further manipulation (e.g., additional sorting, simple statistics) using the DBaseIII Assistant menu or a more powerful statistical package external to DBaseIII. If the sorted file is to be used external to DBaseIII, it must be converted to an appropriate format (e.g., Ascii, Lotus) and may be renamed, again using the Assistant menu.

If the sorted file is to be saved for future use, and other SORTER runs are desired in the interim, the sorted file should either be renamed or transfered to another diskette, using the Assistant menu. This prevents overwriting of the sorted file AECB5.DBF during the next sorting operation.

If it is desired to perform additional SORTER runs on a previously sorted file, that file must be renamed from AECB5.DBF to AECB4.DBF, again using the Assistant menu. The user should be aware that this will eliminate the original database from the hard disk unless the original database is first renamed. The data fields cannot be modified in any way prior to performing a second SORTER run.

The sorting/retrieval options available in the SORTER program as discussed above, are listed in Table 5.1, and also in the program code listings of Appendix 4. Examples of sorting runs are given in Table 5.2 and 5.3. A typical command sequence from database restoration, through sorting, to examination and output of the sorted file is illustrated in Table 5.4.

Sorting and retrieval in DBaseIII is a slow procedure when data files are large. Sorting time can be reduced slightly by compiling SORTER.PRG, using the CLIPPER compiler for DBaseIII programs. However, disk access functions are time limiting, and these are no more rapid in the compiled program. The program uses the DOS copy command which is more rapid than the corresponding DBaseIII function.

In order to minimize user time with the program, all interaction with the user takes place prior to initiation of record sorting and retrieval. Once the search strategy has been specified by question and answer, the strategy is stored in a memory file, and executed by the program with no further user involvement.

There is a limit to the number of memory variables (i.e., answers) that can be stored in memory files as part of the search strategy. Without CLIPPER, this limit is 256 memory variables, which will accommodate the most complex search strategy possible in the SORTER program, as given in Appendix 4. However, addition of new possibilities (e.g., new lakes, species or mines) to the program will increase the number of possible memory variables. With CLIPPER, 2,000 memory variables can be used.

TABLE 5.1: LIST OF SORTING/RETRIEVAL OPTIONS AVAILABLE IN THE SORTING PROGRAM

Data Field	Valid Options
Radionuclide Concentrations in Fish, Water and/or Sediment	Ra-226, Pb-210, U, Po-210, Th-230, Th, Th-232 and/or Th-228 (any range for each radionuclide, Bq/g or Bq/L)*
Provinces or Territories	Saskatchewan, Ontario, NWT and/or BC.
Lakes within Saskatchewan	Beaverlodge, Fredette, Milliken, W1, Shallow, Waterbury, Henday, McMahon, Midwest, Hatchet, Wollaston, Collins Cr, C1, McClean, Tailings Cr, Ace Cr, Fulton, Athabasca, McDonald, Delta, Russell, Gunnar Pit, Horseshoe, Kewen, Key, Wheeler R, Cluff, Cumberland, Sandy, Island, Snake, Dubyna, Donaldson and/or Schmoo
Lakes within Ontario	Dunlop, Esten, Depot, Quirke, McCarthy, Huron, Teasdale, Whiskey, Pecors, Elliot, Camp, Serpent H, Bow, Paudash, Ontario, ELA, Ganaraska R and/or Erie
Lakes within N.W.T.	Great Bear, Sherman and/or Marian R.
Lakes within B.C.	Joan, Lassie, Clark, Sandrift, Trapper, Trapping Cr. and/or Beaverdell Cr
Mines within Saskatchewan	Cluff, Dubyna, Wolly, Midwest, Eldorado, Rabbit, Lor./Gun, Key, Gunnar and/or B-Zone
Mines within Ontario	Elliot and/or Bancroft
Mines within N.W.T.	Rayrock and/or Eldor Port Radium
Mines within B.C.	Blizzard
Mine Status	pre-operational (1), operational (2) and/or decommissioned/decommissioning (3)
Fish Species	L. Trout, Whitefish, N. Pike, B. Bullhead, Sucker, Walleye, L. Chub, Grayling, S. Shiner, R. Whitefish, L.N. Sucker, N. Stickleback, Cisco, T. Perch, Y. Perch, G. Shad, B. Trout, Alewife, R. Trout, Sturgeon, F. Minnow, N.R. Dace, P. Dace and/or Bass

TABLE 5.1: LIST OF SORTING/RETRIEVAL OPTIONS AVAILABLE IN THE SORTING PROGRAM

Data Field	Valid Options
Tissue Type	flesh, bone, whole, stomach, liver, gonad and/or skin
Analytical Laboratory	SRC, AECB, MOH, MOL, EC-WTC, EC-NWRI, Chemex, FWI, Monenco and/or Gulf Minerals
Weight Basis	ash, wet and/or dry
Distance to Mill	any range (km)
Date	any range of months (1-12) and/or year (19XX-19XX)
Composite Data Quality Index	any range (1-10, with equal or user-specified weights for calculation)
Outlier Status (radionuclide ratios, concentrations in fish, zero concentrations and/or BCF's)	any value for each outlier field (0 = outlier or 1)

* U, Th concentration ranges in ug/g (fish, sediment) or ug/L (water).

See Section 3.1 for abbreviation and format conventions on input.

TABLE 5.2: SORTING TO RETRIEVE RECORDS WITH ASH WEIGHT MEASUREMENTS FOR RADIUM-226, LEAD-210 AND TOTAL URANIUM IN WHITEFISH FLESH SAMPLES FROM BEAVERLODGE LAKE

Welcome to the Atomic Energy Control Board's database
on radionuclide levels in fish from Canadian waters.

Is file to be sorted by radionuclides, Y/N? Y
Sort for all available radionuclides, Y/N? N
Sort by Ra-226, Y/N? Y
Sort by Pb-210, Y/N? Y
Sort by Total Uranium, Y/N? Y
Sort by Pb-210, Y/N? N
Sort by Total Thorium, Y/N? N
Sort by Th-230, Y/N? N
Sort by Th-232, Y/N? N
Sort by Th-228, Y/N? N
Sort by Ra-226 fish, Y/N? N
Sort by Ra-226 water, Y/N? N
Sort by Ra-226 sediments, Y/N? N
Sort by Pb-210 fish, Y/N? N
Sort by Pb-210 water, Y/N? N
Sort by Pb-210 sediments, Y/N? N
Sort by Uranium fish, Y/N? N
Sort by Uranium water, Y/N? N
Sort by Uranium sediments, Y/N? N

Is file to be sorted by Provinces or Territories, Y/N? Y
Sort on Saskatchewan, Y/N? Y
Sort on lakes, Y/N? Y
Sort on all lakes, Y/N? N
Sort on Beaverlodge, Y/N? Y
Sort on Fredette, Y/N? N
Sort on Milliken, Y/N? N
Sort on W1, Y/N? N
Sort on Shallow, Y/N? N
Sort on Waterbury, Y/N? N
Sort on Henday, Y/N? N
Sort on McMahon, Y/N? N
Sort on Midwest, Y/N? N
Sort on Hatchet, Y/N? N
Sort on Wollaston, Y/N? N
Sort on Collins Creek, Y/N? N
Sort on C1, Y/N? N
Sort on McClean, Y/N? N
Sort on Tailings Creek, Y/N? N
Sort on Ace Creek, Y/N? N
Sort on Fulton, Y/N? N
Sort on Lake Athabasca, Y/N? N
Sort on McDonald, Y/N? N
Sort on Delta, Y/N? N
Sort on Russell, Y/N? N
Sort on Gunnar Pit, Y/N? N
Sort on Horseshoe, Y/N? N
Sort on Kewen, Y/N? N
Sort on Key Lake, Y/N? N
Sort on Wheeler River, Y/N? N
Sort on Cluff, Y/N? N
Sort on Clumberland, Y/N? N
Sort on Sandy, Y/N? N
Sort on Snake, Y/N? N
Sort on Island, Y/N? N
Sort on Dubyna, Y/N? N
Sort on Donaldson, Y/N? N
Sort on Schmoo, Y/N? N
In Saskatchewan,sort on mines, Y/N? N
Sort on Ontario, Y/N? N
Sort on Northwest Territories, Y/N? N
Sort on British Columbia, Y/N? N

Is file to be sorted by fish species, Y/N? Y
Sort on all fish, Y/N? N
Sort on Lake Trout, Y/N? N
Sort on Whitefish, Y/N? Y
Sort on Northern Pike, Y/N? N
Sort on B. Bullhead, Y/N? N
Sort on Sucker, Y/N? N
Sort on Walleye, Y/N? N
Sort on Lake Chub, Y/N? N
Sort on Grayling, Y/N? N
Sort on S. Shiner, Y/N? N
Sort on R. Whitefish, Y/N? N
Sort on L.N. Sucker, Y/N? N
Sort on Nine-Stickleback, Y/N? N
Sort on Cisco, Y/N? N
Sort on T. Perch, Y/N? N
Sort on Y. Perch, Y/N? N
Sort on G. Shad, Y/N? N
Sort on B. Trout, Y/N? N
Sort on Alewife, Y/N? N
Sort on R. Trout, Y/N? N
Sort on Sturgeon, Y/N? N
Sort on F. Minnow, Y/N? N
Sort on N.R. Dace, Y/N? N
Sort on P. Dace, Y/N? N
Sort on Bass, Y/N? N

Is file to be sorted by tissue type, Y/N? Y
Sort on all tissue types, Y/N? N
Sort on flesh, Y/N? Y
Sort on bone, Y/N? N
Sort on whole fish, Y/N? N
Sort on stomach, Y/N? N
Sort on liver, Y/N? N
Sort on gonad, Y/N? N
Sort on organs, Y/N? N
Sort on skin, Y/N? N

Is file to be sorted by analytical lab., Y/N? N

Is file to be sorted by weight basis, Y/N? Y
Sort on all weight basis, Y/N? N
Sort on ash, Y/N? Y
Sort on wet, Y/N? N
Sort on dry, Y/N? N

Is file to be sorted by distance to mill, Y/N? N
Is file to be sorted by the date, Y/N? N
Do you want to do calcs on the quality data, Y/N? N

TABLE 5.3: SORTING TO RETRIEVE RECORDS WITH WET WEIGHT RADIUM-226 MEASUREMENTS BETWEEN ZERO AND 1 Bq/g IN WHOLE ACE CREEK SUCKERS

```
Welcome to the Atomic Energy Control Board's database
on radionuclide levels in fish from Canadian waters.

Is file to be sorted by radionuclides, Y/N? Y
Sort for all available radionuclies, Y/N? N
Sort by Ra-226, Y/N? Y
Sort by Pb-210, Y/N? N
Sort by Total Uranium, Y/N? N
Sort by Po-210, Y/N? N
Sort by Total Thorium, Y/N? N
Sort by Th-230, Y/N? N
Sort by Th-232, Y/N? N
Sort by Th-228, Y/N? N

Sort by Ra-226 fish, Y/N? Y
What is the logical option:
   (1)  =
   (2)  <
   (3)  >
   (4)  > and <
   (5)  all
Values are in Bq/g

4
What is the value greater than -0.05
What is the value less than 1.005

Sort by Ra-226 water, Y/N? N
Sort by Ra-226 sediments, Y/N? N
Sort by Pb-210 fish, Y/N? N
Sort by Pb-210 water, Y/N? N
Sort by Pb-210 sediments, Y/N? N
Sort by Uranium fish, Y/N? N
Sort by Uranium water, Y/N? N
Sort by Uranium sediments, Y/N? N

Is file to be sorted by Provinces or Territories, Y/N? Y
Sort on Saskatchewan, Y/N? Y
Sort on lakes, Y/N? Y
Sort on all lakes, Y/N? N
Sort on Beaverlodge, Y/N? N
Sort on Fredette, Y/N? N
Sort on Milliken, Y/N? N
Sort on W1, Y/N? N
Sort on Shallow, Y/N? N
Sort on Waterbury, Y/N? N
Sort on Henday, Y/N? N
Sort on McMahon, Y/N? N
Sort on Midwest, Y/N? N
Sort on Hatchet, Y/N? N
Sort on Wollaston, Y/N? N
Sort on Collins Creek, Y/N? N
Sort on C1, Y/N? N
Sort on McClean, Y/N? N
Sort on Tailings Creek, Y/N? N
Sort on Ace Creek, Y/N? Y
Sort on Fulton, Y/N? N
Sort on Lake Athabasca, Y/N? N
Sort on McDonald, Y/N? N
Sort on Delta, Y/N? N
Sort on Russell, Y/N? N
Sort on Gunnar Pit, Y/N? N
Sort on Horseshoe, Y/N? N
Sort on Kewen, Y/N? N
Sort on Key Lake, Y/N? N
Sort on Wheeler River, Y/N? N
Sort on Cluff, Y/N? N
Sort on Clumberland, Y/N? N
Sort on Sandy, Y/N? N
Sort on Snake, Y/N? N
Sort on Island, Y/N? N
Sort on Dubyna, Y/N? N
Sort on Donaldson, Y/N? N
Sort on Schmoo, Y/N? N
In Saskatchewan,sort on mines, Y/N? N
Sort on Ontario, Y/N? N
Sort on Northwest Territories, Y/N? N
Sort on British Columbia, Y/N? N

Is file to be sorted by fish species, Y/N? Y
Sort on all fish, Y/N? N
Sort on Lake Trout, Y/N? N
Sort on Whitefish, Y/N? N
Sort on Northern Pike, Y/N? N
Sort on B. Bullhead, Y/N? N
Sort on Sucker, Y/N? Y
Sort on Walleye, Y/N? N
Sort on Lake Chub, Y/N? N
Sort on Grayling, Y/N? N
Sort on S. Shiner, Y/N? N
Sort on R. Whitefish, Y/N? N
Sort on L.N. Sucker, Y/N? N
Sort on Nine-Stickleback, Y/N? N
Sort on Cisco, Y/N? N
Sort on T. Perch, Y/N? N
Sort on Y. Perch, Y/N? N
Sort on G. Shad, Y/N? N
Sort on B. Trout, Y/N? N
Sort on Alewife, Y/N? N
Sort on R. Trout, Y/N? N
Sort on Sturgeon, Y/N? N
Sort on F. Minnow, Y/N? N
Sort on N.R. Dace, Y/N? N
Sort on P. Dace, Y/N? N
Sort on Bass, Y/N? N

Is file to be sorted by tissue type, Y/N? Y
Sort on all tissue types, Y/N? Y

Is file to be sorted by analytical lab., Y/N? N

Is file to be sorted by weight basis, Y/N? Y
Sort on all weight basis, Y/N? N
Sort on ash, Y/N? N
Sort on wet, Y/N? Y
Sort on dry, Y/N? N
```

TABLE 5.4: TYPICAL COMMAND SEQUENCE FROM DATABASE RESTORATION TO EXAMINATION AND OUTPUT OF SORTED FILE

Command[1]	Function
RESTORE A:C:\DBASE3*.*	restore database from drive A to DBASE3 sub-directory on drive C
CD\DBASE3	enter DBASE3 sub-directory
COPY A:*.*	copy programs from drive A to DBASE3 sub-directory on drive C
DBASE	enter DBASE
[ESC]	obtain dot prompt
.SET DEFAULT TO C	define hard disk as default drive
.DO SORTER	initiate sorting and retrieval program
.DISPLAY LAKE, SPECIES, RA226FISH	print these fields on screen
.DISPLAY LAKE, SPECIES, RA226FISH TO PRINTER	print these fields on printer
.BROWSE	initiate browsing through sorted file (data changes can be made in this mode)
.COPY TO B: newfile RA226FISH TYPE SDF	prints this field in an Ascii format file called newfile on drive B

[1] Refer to DBaseIII Plus manual for details on each command and many other commands available.

6.0 STATISTICAL DATA SUMMARIES

Summary statistics can be produced from the database, or retrieved subsets of the database, by using built-in DBaseIII Plus functions, or other statistical software packages. The menu-driven statistical capabilities of DBaseIII are limited to computation of means, sums and counts. More sophisticated statistical functions can be programed in DBaseIII; however, it is easier to use an external statistical package to perform these analyses.

In most cases, the user will be performing statistical operations on a retrieved subset of the database, rather than the entire file. This sorted file is then converted to a format compatible with the statistical package. The SPSS/PC+ statistical package was used to generate the summary statistics and histograms presented in this section and Appendix 2.

The SPSS package requires Ascii format data files. The sorted file AECB5.DBF was converted to Ascii format and transferred to a diskette using the Assistant menu in DBaseIII Plus. SPSS command files were stored on the same diskette. The SPSS commands used to generate summary statistics and histograms are shown in Table 6.1. The user is referred to the SPSS manual for detailed description SPSS commands and statistical procedures.

Populations were defined for purposes of statistical summary, as for outlier detection, according to lake names, fish species, tissue type and weight basis of radionuclide concentrations. Each population was characterized by a unique combination of these variables. Frequency distributions and summary statistics were generated within each population for each radionuclide measured in ten or more samples. Frequency histograms are presented in Appendix 2, with complete summary statistics including mean, standard deviation, standard error, variance, median, mode, skewness, kurtosis, standard errors of skewness and kurtosis, minimum, maximum and range.

Radionuclide concentrations were log transformed prior to generation of frequency histograms and summary statistics. This transformation tended to normalize the distributions, improving their symmetry. Prior to transformation logarithmic distributions were typical. Such distributions are strongly skewed.

Geometric means are the appropriate measure of central tendency in logarithmic distributions. These are computed on the log scale and back-transformed to the original scale by calculation of the antilog. Geometric means and maxima for each radionuclide in each population are listed in Table 6.2.

Most of the populations in Table 6.2 represent samples collected by Swanson (1982, 1983, 1985) in Northern Saskatchewan. Few other authors have collected large numbers of samples of particular fish species in a single locality for subsequent radionuclide determinations. Samples of rainbow trout from Lake Ontario analyzed for Ra-226 by Environment Canada (Joshi, 1984) are the only large collections in Ontario.

The Saskatchewan data illustrate characteristic differences between tissues within fish species from particular locations. For example, Ra-226 concentrations are typically higher in bone than in other tissues, while uranium concentrations tend to be higher in bone and skin than in flesh.

Geographical patterns are also suggested by the Saskatchewan data, with higher radionuclide concentations in fish from Ace Creek, Tailings Creek and Beaverlodge Lake, and lower concentrations in fish from Fredette Lake and Milliken Lake. However, differences in fish species and weight basis complicate these comparisons.

Data for Ra-226, Pb-210 and total uranium are well represented by determinations in large collections. Limited data are available for Po-210 in liver and stomach tissues. The only data for total thorium in a large fish collection is provided by BEAK's (1980) analysis of whitefish in Russell Lake. More data are needed for thorium and thorium isotopes in fish tissue.

TABLE 6.1: SPSS COMMANDS USED TO GENERATE SUMMARY STATISTICS AND HISTOGRAMS

```
data list file='b:spssin' free/recno ra226  pb210 urant po210 thot.

if (ra226 le 0)ra226=-999.
if (pb210 le 0)pb210=-999.
if (urant le 0)urant=-999.
if (po210 le 0)po210=-999.
if (thot le 0)thot=-999.
missing value ra226 pb210 urant po210 thot (-999).

compute ra=lg10(ra226).
compute pb=lg10(pb210).
compute ur=lg10(urant).
compute po=lg10(po210).
compute th=lg10(thot).

frequencies vars=ra to th
/format=notable
/histogram
/statistics=all.
```

Note: spssin is an Asci file containing six fields which was generated as output from DBaseIII and resides on a diskette in drive B.

TABLE 6.2: GEOMETRIC MEAN AND MAXIMUM CONCENTRATIONS OF RADIONUCLIDES IN FISH TISSUE

Population[2]	Radium-226 (Bq/g)[1]			Lead-210 (Bq/g)			Polonium-210 (Bq/g)			Uranium (ug/g)			Thorium (ug/g)		
	N	Mean	Max	N	Mean	Max	N	Mean	Max	N	Mean	Max	N	Mean	Max
Milliken Lake, Sucker, skin, wet	24	0.0006	0.518	21	0.002	0.045				36	0.062	5.62			
Milliken Lake, Sucker, stomach, wet	20	0.019	0.160	23	0.065	0.180	12	0.080	0.140	28	1.507	14.0			
Milliken Lake, Whitefish, liver, wet							14	0.026	1.199						
Milliken Lake, Whitefish, stomach, wet							16	0.038	0.130						
Lake Ontario, Rainbow Trout, whole, wet	20	1.722	71.45							10	0.420	1.20			
Russell Lake, Whitefish, flesh, ash													10	0.993	3.80
Sandy Lake, Pike, bone, ash	11	0.011	0.020												
Sandy Lake, Pike, flesh, ash	10	0.014	0.040							10	0.583	1.20			
Sandy Lake, Whitefish, bone, ash	10	0.013	0.020												
Ace Creek, Sucker, whole, ash	16	0.897	2.999	15	0.455	1.400				16	47.32	129.1			
Ace Creek, Sucker, whole, wet	14	0.044	0.239	14	0.018	0.117				14	2.360	7.261			
Beaverlodge Lake, Whitefish, bone, ash	42	0.144	1.099	41	0.109	0.550				42	43.95	119.9			
Beaverlodge Lake, Whitefish, flesh, ash	39	0.072	9.397	37	0.109	4.898				39	6.932	52.00			
Beaverlodge Lake, Whitefish, skin, ash	36	0.186	0.650	40	0.117	0.800				40	36.90	95.94			
Beaverlodge Lake, Whitefish, bone, wet	43	0.039	0.292	42	0.029	0.151				43	11.27	38.46			
Beaverlodge Lake, Whitefish, flesh, wet	31	0.0004	0.070	33	0.001	0.030				39	0.055	4.797			
Beaverlodge Lake, Whitefish, skin, wet	37	0.001	0.160	42	0.006	0.110				41	1.968	39.72			
Beaverlodge Lake, Whitefish, stomach, wet	29	0.338	6.501	27	0.400	4.498				29	72.44	639.7			
Tailings Creek, Chub, whole, ash	20	0.771	190.1	20	0.406	59.98				18	33.63	69.02			
Tailings Creek, Chub, whole, wet	18	0.013	0.115	18	0.008	0.056				18	1.167	2.328			
Fredette Lake, Whitefish, skin, ash	13	0.019	0.040	13	0.079	1.000				18	1.828	17.99			
Fredette Lake, Whitefish, bone, wet				13	0.008	0.017				18	0.369	6.166			
Fredette Lake, Whitefish, flesh, wet				10	0.0004	0.003				16	0.009	0.047			
Fredette Lake, Whitefish, liver, wet							10	0.029	0.200	16	0.325	5.120			
Fredette Lake, Whitefish, skin, wet	13	0.001	0.002	12	0.002	0.005				18	0.106	0.995			
Fredette Lake, Whitefish, stomach, wet	11	0.037	0.400	10	0.149	1.099	12	0.216	2.000	12	12.50	93.97			
Milliken Lake, Sucker, bone, ash	14	0.028	0.700	19	0.041	1.400				33	1.054	6.998			
Milliken Lake, Sucker, flesh, ash	14	0.025	0.190	17	0.056	0.300				31	0.386	5.395			
Milliken Lake, Sucker, skin, ash	24	0.011	0.030	20	0.035	0.250				36	1.213	63.97			
Milliken Lake, Sucker, bone, wet	14	0.006	0.064	18	0.008	0.022				35	0.297	1.607			
Milliken Lake, Sucker, flesh, wet	13	0.0003	0.0009	14	0.0005	0.002				31	0.008	0.433			
Milliken Lake, Sucker, gonad, wet										13	0.028	0.400			
Milliken Lake, Sucker, liver, wet										37	0.090	1.099			
Beaverlodge Lake, Sucker, liver, wet							13	0.018	0.400		-				
Beaverlodge Lake, Sucker, stomach, wet							17	0.390	2.500		-				
Beaverlodge Lake, Whitefish, gonad, wet										14	0.384	2.301			
Beaverlodge Lake, Whitefish, liver, wet							18	0.022	0.190	36	2.061	14.00			
Fredette Lake, Whitefish, bone, ash				13	0.034	0.120				18	1.419	21.98			
Fredette Lake, Whitefish, flesh, ash				12	0.047	0.200				16	0.968	4.898			

[1] Radium concentrations in Bq/g, except in Lake Ontario where units are pCi/kg.

[2] Population excludes values less than detection.

7.0 DATABASE MAINTENANCE

Addition of data records to the database AECB4.DBF may introduce new alphanumeric values of the sorting criterion variables (e.g., new lakes or mines). When this occurs the SORTER program should be modified in order to permit sorting and retrieval of the new records based on these criterion variables. Thus addition of data and program modification are related aspects of database maintenance. They are discussed in Sections 7.1 and 7.2 respectively.

7.1 Addition of Data

It is essential that new data records follow the same format as previous records with respect to number of fields, field width, spelling of alphanumeric values, designation of missing values and designation of values less than detection. It is also essential that the assumptions involved in determination of numeric values (e.g., distance to mill) and matching of fish samples with water and sediment samples be consistently applied. These conventions are described in Sections 3.1 and 3.2. Any deviation from these conventions may cause failure of the SORTER program to retrieve new records.

When new data records contain new alphanumeric values (e.g., new lakes or mills) spelling conventions should be recorded (see Section 3.1) and subsequently followed. These conventions must also be incorporated into the SORTER program.

7.2 Program Modifications

The procedures for creating and modifying DBaseIII programs are described in the DBaseIII Plus manual. The user is referred to this manual for a complete list of DBaseIII programing commands. To edit a DBaseIII program, the user types MODIFY COMMAND file name, following the dot prompt. Filename is the name of the program without the .PRG extension. Once inside the program, cursor keys are used to find the lines and characters to be changed, and the insert key is used to add lines.

A list of programs, their functions and index files which they create is given in Table 7.1. Program listings are included in Appendix 4.

TABLE 7.1: SORTER PROGRAM STRUCTURE AND FUNCTION

Program	Memory or Index Files Created	Function
SORTER.PRG		master program, calls user interface programs and SORT1
SORTPRE1.PRG	AECB1.MEM	user interface program, asks questions about radionuclides
SORTPRE2.PRG	AECB2.MEM	user interface program, asks questions about lakes and mines
SORTPRE3.PRG	AECB3.MEM	user interface program, asks questions about remaining sorting criteria
SORT1.PRG		calls all other programs, according to search strategy stored in memory files
SORTRAD.PRG		sorts by radionuclides measured
SORTRAD2.PRG		sorts by concentrations of individual radionculides
SORTAREA.PRG	AECBMINE.NDX AECBAREA.NDX	sorts by province, lake, mine and status
SORTFISH.PRG	AECBFISH.NDX	sorts by fish species
SORTISS.PRG	AECBTISS.NDX	sorts by tissue type
SORTLAB.PRG	AECBLAB.NDX	sorts by analytical laboratory
SORTWT.PRG	AECBWT.NDX	sorts by weight basis
SORTDIST.PRG		sorts by distance to mill
SORTDATE.PRG		sorts by sample date
CALCQUAL.PRG		sorts by outlier status and composite data quality index

Program listings in Appendix 4.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The Canadian database of uranium and thorium decay-series radionuclide concentrations in fish can be characterized by a number of data deficiencies which lead to recommendations for improvement of the database in future studies:

1. Documentation of reported data is generally deficient in several aspects pertinent to evaluation of data quality and comparability between studies. In particular, sample storage times and conditions are seldom described, and detection limits and relative errors are seldom defined. Plans for future studies should include requirements for full documentation of sampling procedure, storage methods, tissue source and preparation, analytical procedures, weight basis of results, control samples used, detection limits, relative errors and methods of determining these statistics.

2. Data for concentrations of total thorium, thorium isotopes and polonium-210 in fish are sparse. Few studies report ten or more determinations of these radionuclides in the same water body, fish species and tissue type. Representative collections of fish for determination of these parameters in areas of high ambient concentration should be a research priority. The high dose conversion factors which have been reported for thorium isotopes, in particular, emphasize the importance of knowledge concerning concentrations and bioaccumulation potential in fish.

3. Data for concentrations of uranium and thorium decay-series radionuclides in Canadian fish originate primarily from Saskatchewan. More studies of Ontario fish are needed to adequately represent fish species and populations in Canadian uranium mining and milling areas.

4. Many of the fish samples analyzed for uranium and thorium decay-series radionuclides in Canada are not easily associated with corresponding water or sediment determinations from the same location and time period. Routine collection of such ambient information in future studies of radionuclide content in fish would be useful for estimation of bioaccumulation potential.

5. Analytical bias between laboratories is difficult to assess in the absence of fish tissue standards for uranium and thorium decay-series radionuclides. Development of such standards would increase the confidence with which data from different studies can be compared. Until such time as these standards become available, interlaboratory exchange of samples during each study is the best method of assessing possible biases and incompatibilities between data sets.

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